Use of Computational Fluid Dynamics to Investigate Natural and Mechanically Induced Flows in an Aerated Lagoon

Dale de Kretser, Brown & Root Services Asia-Pacific Pty Ltd, Brent Matthews, CFD Research Pty Ltd, and Mike Williams, Australian Paper Pty Ltd

Aerated lagoons are frequently used to treat dilute wastewater from pulp and paper mills. One problem with their use is the settling and resultant biological degradation of solids. To remove these solids, costly and disruptive techniques need to be employed. Furthermore, degraded solids which leave the lagoon are difficult to settle in downstream processes, with the result that they often reach the receiving environment. Historically, mixing in lagoons was based on empirical rules of power input per unit volume, without direct knowledge of the resultant water velocities. The development of computational fluid dynamics (CFD) has enabled fluid velocities at any point to be determined, with obvious benefits for controlling the efficiency of the mixing and minimizing solids settlement.

Australian Paper's Maryvale mill is Australia's largest integrated pulp and paper producer. It produces over 700 tons per day of fine papers and around 800 tons per day of packaging grade papers. Its brands include the premium photocopy paper Reflex, as well as linerboard for box manufacture. It also generates approximately 55 ML/day of wastewater which is treated through its secondary wastewater treatment system. The main component of this treatment system is an aerated lagoon (Pond 1A, shown in Figure 1) which has an average depth of 4.3 m and a capacity of 375 ML. The pond is approximately 550m long and 150 - 250m wide. It contains a dividing wall in the middle that extends from the inlet side to approximately four-fifths of the pond length. Aeration and mixing of the lagoon are provided by six 55 kW aerators and sixteen 45 kW aerators, giving a total connected power of around 1050 kW and an average mixing intensity of 2.8 W/m^3. The mixing energy is not uniform throughout the lagoon, however, and varies from 3.3 W/m^3 near the inlet (where the 55 kW aerators are located), to 1.4 W/m^3 in other parts.

Figure 1: An aerial view of the lagoon shows mixing taking place by aerators located just below the water surface.

FLUENT
WWW.FLUENT.COM

EXHIBIT
tabbies
3225-5A

Although the total connected power is 1050 kW, the organic load only requires approximately 630 kW. Thus there is around 420 kW of aerator power that is available for the mixing process alone. The purpose of this study was to determine if mixers could be used in place of aerators to increase the degree of mixing and there minimize the settlement of solids in the lagoon. To gain this insight, a computational fluid dynamics (CFD) program (FLUENT) was used to calculate the water velocities throughout the lagoon under different combinations of aerators and mixers.

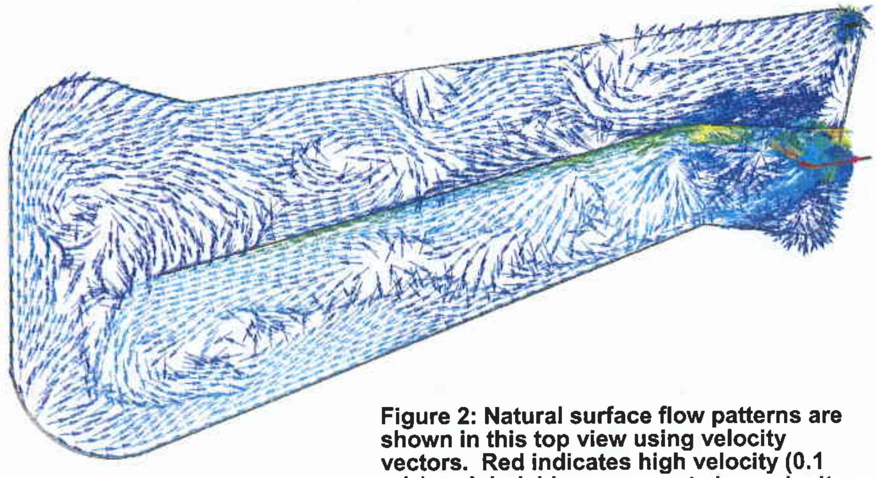

Figure 2: Natural surface flow patterns are shown in this top view using velocity vectors. Red indicates high velocity (0.1 m/s) and dark blue represents low velocity (<0.01 m/s).

Base flow case

The first stage of the investigation examined natural flow patterns present in the lagoon. It found that there were was a significant degree of short-circuiting occurring, with the majority of the flow proceeding along a dividing wall inside the lagoon. This finding mirrored the results of earlier flow studies carried out by Australian Paper using surface flotation devices. Figure 2 shows the surface profile of the flow patterns, while Figure 3 presents a close up of the inlet area. Some key findings from the natural flow case were:

1. The Coanda effect caused the inflowing jet of water to angle towards the dividing wall soon after entering the lagoon. The Coanda effect occurs when recirculating flow becomes a region of low pressure, causing it to attract nearby inflow because it is the path of least resistance. In the lagoon, the dividing wall retards the main flow due to friction, causing a recirculation pattern to develop, which subsequently redirects the inflow.
2. The majority of the flow travelled along the dividing wall.
3. There was a recirculation flow back to the inlet along the outer bank of the first leg of the lagoon.
4. There were several dead zones throughout the lagoon, resulting in the effective detention time being much lower than the theoretical value.
5. Water velocities in the second half of the lagoon were much lower than on the inlet side.

Aerator and mixer flow patterns

The second stage examined the individual flow patterns generated by the existing aerators used in the lagoon and one type of mixer which may be added to the lagoon in the future. The simulations were done in a rectangular 70m-square block with 4.3m depth, rather than the lagoon itself. The results showed that the aerator provides very good surface mixing (as can be seen from the aerial photograph in Figure 1), but is relatively inefficient at depth, while the mixer promotes good mixing at depth, but is less effective on the surface. Figure 4 shows a velocity plot of the

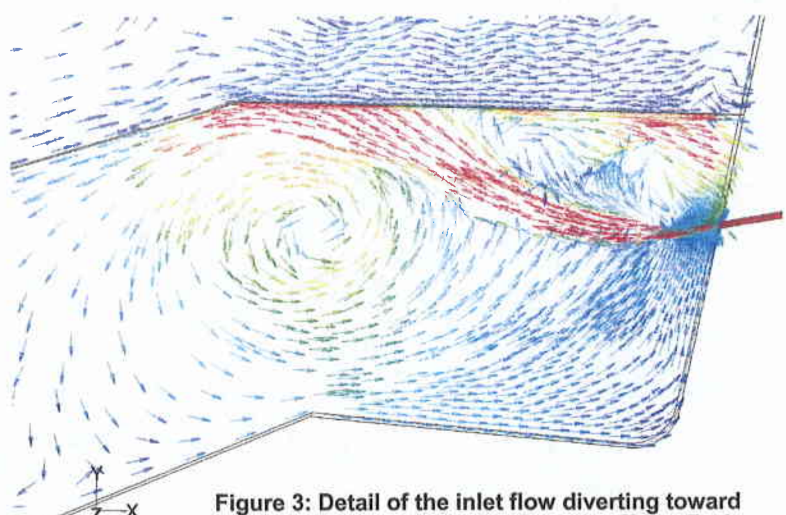

Figure 3: Detail of the inlet flow diverting toward the dividing wall due to the Coanda effect. Red indicates high velocity (0.1 m/s) and dark blue represents low velocity (<0.01 m/s).

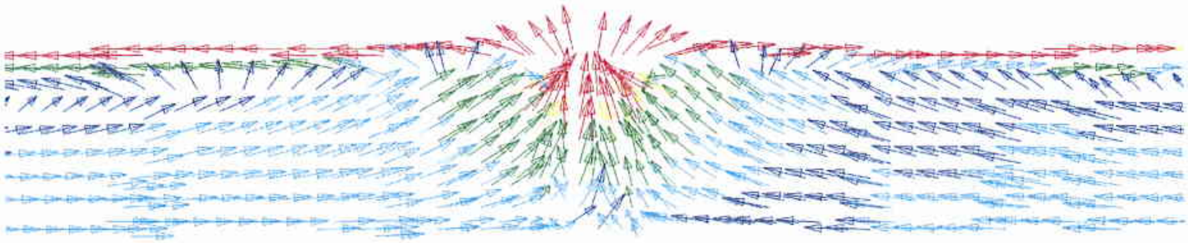

Figure 4: A cross-sectional view of the aerator flow patterns in water with a 4.3m depth. Red indicates high velocity (0.5 m/s) and dark blue represents low velocity (<0.05 m/s).

flow patterns from a 55 kW surface aerator. It shows that the aerator draws water up from depth and expels it radially across the water surface. Flow patterns of the mixer (not shown) were found to be virtually the inverse of the aerator, drawing water down from the surface and expelling it radially at depth.

Visual inspection of the lagoon surface showed that the 55 kW aerators appeared to provide well-mixed conditions for a radius of 25 m from the aerator. As the depth of the lagoon was 4.3 m, the volume of the well-mixed region around the aerator was approximately 8.5 ML. This volume was subjected to a mixing intensity of approximately 6.5 W/m^3. Suspended solids analysis of the water column within this region confirmed that the majority of solids were maintained in suspension.

The CFD analysis of the aerator flow patterns showed that the minimum water velocity within this 8.5 ML body of water was approximately 0.03 m/s. It was therefore concluded that if a minimum water velocity of 0.03 m/s could be maintained across the lagoon, the majority of solids would remain in suspension.

Developing the arrangement of aerators and mixers

The final stage of the investigation combined the results of the first two stages to produce overall flow patterns for various parts of the lagoon under the influence of both aerators and mixers, with an emphasis on the inlet end of the lagoon. Combinations of three aerators and three mixers were investigated. The combined flow patterns for the inlet section of the lagoon are shown in Figure 5. The key findings from this phase of the analysis were:

1. The combination of aerators and mixers provided good surface agitation, with the majority of the inlet area having a velocity of 0.05 - 0.1 m/s.
2. The mixers provided good mixing in the lower parts of the water column, with the 0.05 - 0.1 m/s velocity band extending to a diameter of at least 40m.
3. There was a good exchange of water between the surface and the base of the lagoon due to the complimentary action of the aerators and mixers. Figure 6a shows the path lines of massless particles as they travel between the aerators and mixers. Figure 6b shows a cross-sectional view of a vertical plane, where the complimentary flow patterns produced by a mixer and an aerator are displayed.

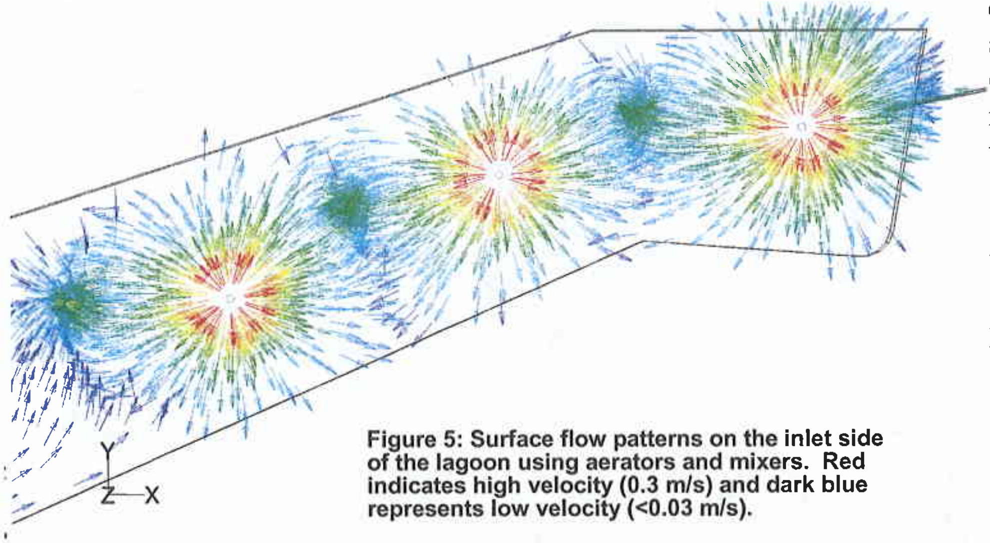

Figure 5: Surface flow patterns on the inlet side of the lagoon using aerators and mixers. Red indicates high velocity (0.3 m/s) and dark blue represents low velocity (<0.03 m/s).

Requirements for the use of CFD

In order to effectively use the CFD process, certain information needs to be provided. For this investigation this information included:

1. Reasonably accurate details of the lagoon dimensions so that a grid could be created on which the flow equations were solved.
2. Physical properties of the lagoon contents, such as density, viscosity, and temperature.
3. Location, dimensions, alignment and flow rate of the lagoon inlet and outlet.
4. Location, dimensions and operating characteristics (such as speed of rotation and pumping capacity) of the aerators and mixers. The pumping action of the aerators and mixers were represented as momentum sources in the CFD program.

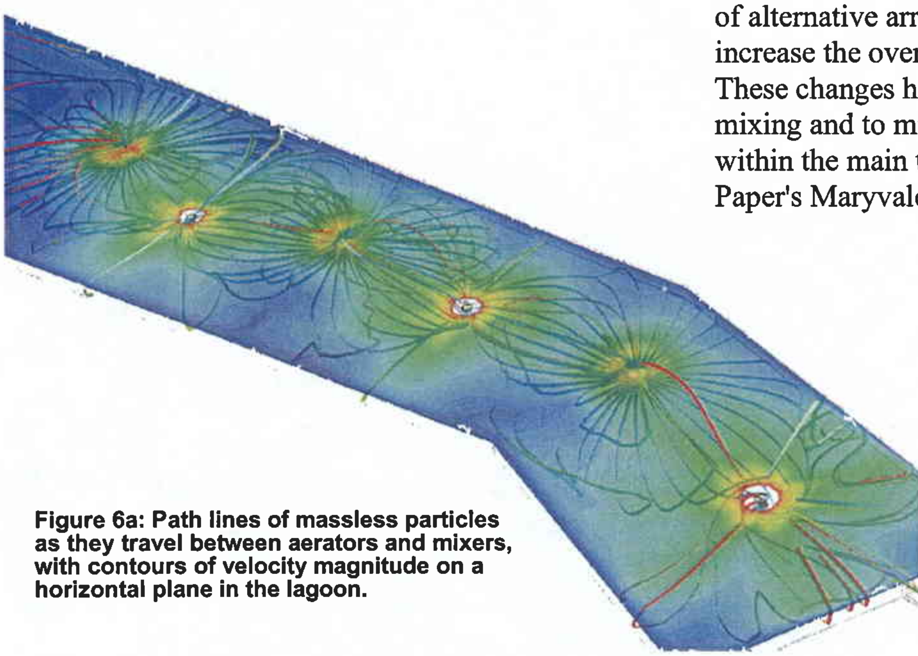

Figure 6a: Path lines of massless particles as they travel between aerators and mixers, with contours of velocity magnitude on a horizontal plane in the lagoon.

Conclusions

Computational fluid dynamics (CFD) involves solving the fundamental equations describing fluid motion, with minimal empirical input or a priori assumptions about the flow. If required, additional equations can be solved to model processes such as heat transfer, reactions and particle transport. By solving the flow at every point in the domain, a very detailed three-dimensional picture of the velocity field can be determined, along with results for other relevant variables such as temperature, chemical species, particle concentrations, or turbulence, for example. These results can be used to better understand a process and to guide changes that could lead to improved operation or optimization of the process.

The result of the investigation was the development of alternative arrangements of aerators and mixers to increase the overall water velocity in the lagoon. These changes helped to improve the degree of mixing and to minimize accumulation of solids, within the main treatment lagoon at Australian Paper's Maryvale mill wastewater treatment system.

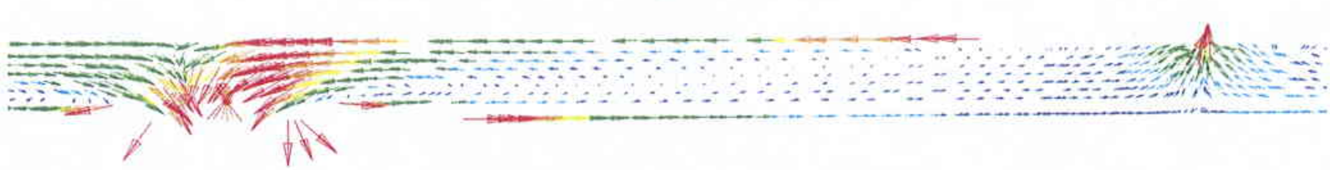

Figure 6b: A cross-section view of the complimentary mixing of a down-pumping mixer (left) and an adjacent up-pumping aerator (right). Red indicates high velocity (0.3 m/s) and dark blue represents low velocity (<0.03 m/s).